

## Self-Resolving Jet Reactions

S. Brodsky (SLAC)

Work in progress with

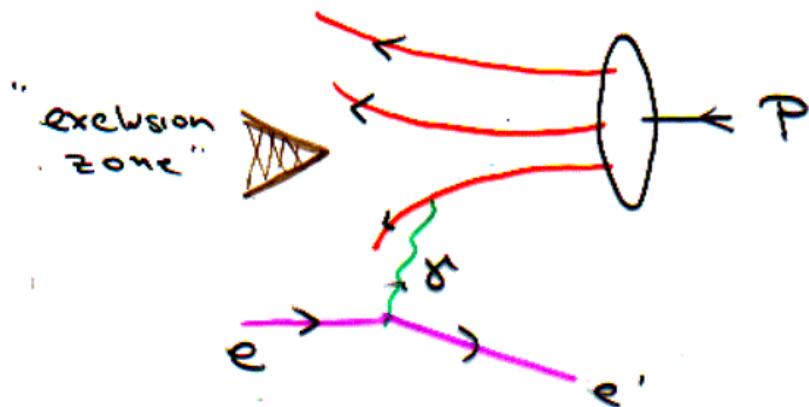
P. Hoyer  
M. Diehl  
S. Peigne

eRHIC Workshop

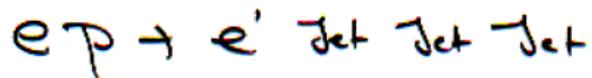
BNL Dec. 3-4, 1999

Hoyer  
Perugia  
Dietl  
EGB

## "Self-Resolving" Jet Reaction



Coulomb dissociation of proton



$$\textcircled{1} \quad \frac{|k_{\perp i}|}{x_i p^+} > \Theta_0 \quad x_i = \frac{k_{\perp i}^+}{p^+}$$

$$\textcircled{2} \quad \sum x_i = 1$$

$$\therefore m^2 = \sum_i \left( \frac{k_{\perp i}^2 + m^2}{x_i} \right)_i > \sum_i x_i (p^+ \Theta_0)^2 \\ = (p^+ \Theta_0)^2$$

Light-Cone Wavefunctions  
 and QCD Phenomena

Non-Perturbative  
QCD

$\{\Psi_n\}$ : translation: hadrons  $\Rightarrow$   $q_1 q_2 \dots$

$$x_i, \vec{k}_{\perp i}, \lambda_i$$

$$x_i = \frac{k_i^+}{p^+} = \frac{h_i^0 + h_i^z}{p^0 + p^z}$$

Fixed  $\mathcal{N} = t + z/c$

$$|\Psi\rangle = \sum_n |n\rangle \Psi_n(x_i, \vec{k}_{\perp i}, \lambda_i)$$

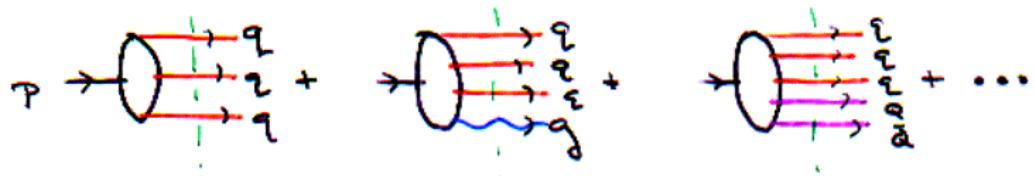
$\sim$  free  $q_1 q_2 \dots$  basis

$$\sum_{i=1}^n x_i = 1, \quad \sum_{i=1}^n \vec{k}_{\perp i} = 0$$

"Light-cone Fock expansion"

boost invariant      Frame-indep.

## Light-Cone Fock Representation of Hadrons



$$|P\rangle = \sum_n |n\rangle \Psi_n(x_i, \bar{k}_{xi}, \lambda_i)$$

$\wedge \sum x_i = 1, \sum \bar{k}_{xi} = 0$

- \* Explicit solutions      QCD(1+1), "collinear" QCD  
using "DLCQ"      SJB, Pauk, Harriskele  
Antonuccio, Dolley
- \* Calculate structure       $q(x), \bar{q}(x), Q(k)$   
functions      spin-dependence
- \* Calculate Regge behaviour       $x \rightarrow 0, \text{BFKL}$   
using "ladder relations"      spin-dependence  
Mueller, SJB, Antonuccio, Dolley
- \*  $x \rightarrow \pm$  constraints      Lepage, SJB, Burkhardt, Sch
- \* Properties of heavy quark sea:  $s(x) \neq \bar{s}(x)$   
extrinsic vs intrinsic      Kogut      Ma  
physics of  $\Delta \Sigma$ , anomaly      Ball      Schmitz  
Ball      SJB  
Schmitz      Schlumpf

G.P. Lepage  
SJB

## Light-Cone Wavefunctions

encode all helicity, transversity  
distributions

$$Q_{\lambda/\lambda_p} = \int \left| \begin{array}{c} \rightarrow \\ \lambda_p \end{array} \right| \rightarrow \left| \begin{array}{c} x, \lambda \\ \rightarrow \\ \rightarrow \\ \rightarrow \end{array} \right|^2$$

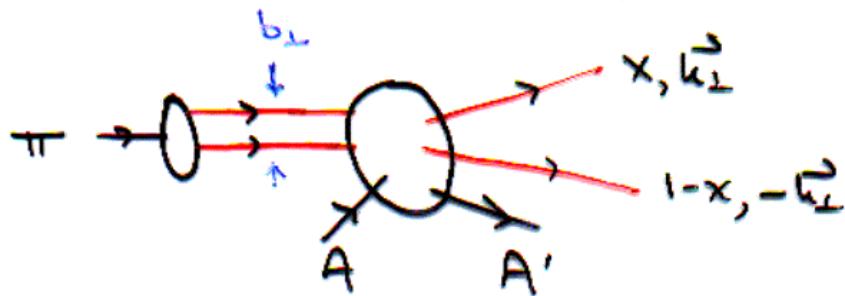
$$Q_{\lambda/\lambda_p}(x, \Lambda) = \sum_{n,\xi} \int \left| \Psi_{n,\lambda_p}^{(\Lambda)}(x_i, \tilde{k}_{2i}, \lambda_i) \right|^2 \prod_{j=1}^2 dx_j \prod_{j=1}^2 dk_j$$

$$\delta(\sum_i x_i - 1) \delta(\sum_i \tilde{k}_i)$$

$$\delta(x - x_e) \delta_{\lambda, \lambda_e}$$

$$\Theta(\Delta^2 - m_i^2)$$

Test of Color Transparency  
and Measurement of  $\Psi_\pi(x, \vec{u}_\perp)$



\* "Nuclear Filter"

Small color-singlet components pass  
large components absorbed

A. Mueller  
SJB

- \* Diffractive production of di-jets  
nucleus left intact

G. Bertsch  
J. Gunion  
SJB F. Goldhaber

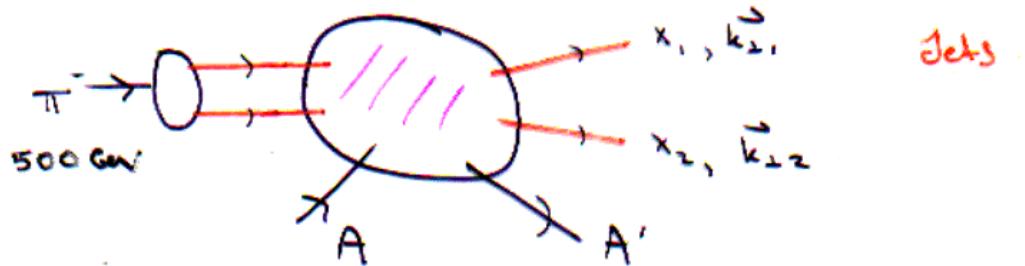
$$\Psi_\pi(x, \vec{u}_\perp)$$

- \* E791 Fermilab D. Ashery  
R. Weiss-Bobai et al

Frankfurt  
Miller  
Strikman

F. D. Gerasimov, V. V. Kabanov  
S. V. Shurygin

## Direct Measurement of Valence Wavefunctions $\downarrow$ Hadrons



$$x_1 + x_2 \approx 1$$

$$\Delta P_L, \Delta P_T < \frac{1}{R_A}$$

$$\vec{k}_{\perp 1} + \vec{k}_{\perp 2} \approx 0$$

color transparency

Coherent  
on  
nucleus

$$\Rightarrow M_A \sim A'$$

$$\int \frac{d\sigma}{dt} dt \sim A^{2/3}$$

Measures

$$\Psi_{q\bar{q}/\pi}(x, \vec{k}_\perp)$$

Bertsch, Gunion, Goldhaber, SJB

E791

X Frankfurt, Miller, Strikman

## DI - JETS ANALYSIS

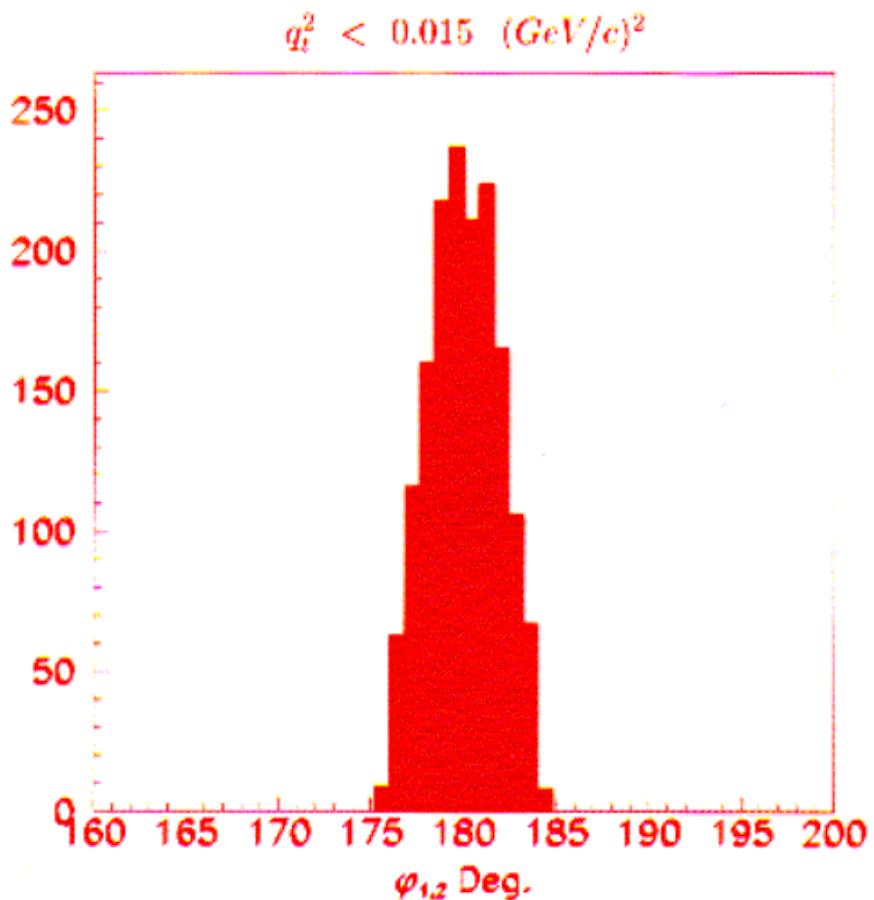
Used  $\sim 1/3$  of E791 data

Basic Cuts:

1.  $\Sigma p_x > 450 \text{ GeV}/c$  (in charged tracks)

2. Jet Finder - JADE Algorithm

3. Select Di-Jet events

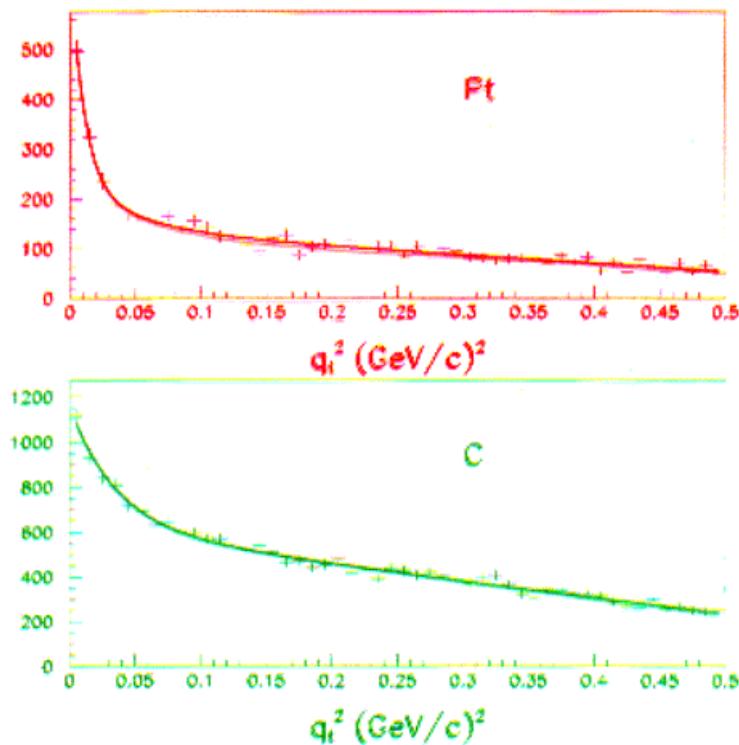


## DIFFRACTIVE DI - JETS

$$\pi A \rightarrow \text{Jet Jet } A$$

- Diffractive DI-JETS are identified through the  $e^{-bq_t^2}$  dependence of their yield.
- $b = \frac{\langle R^2 \rangle}{3}$ ,  $R$  is the nuclear radius:  
 $R_C = 2.44 \text{ fm}$ ,  $R_{Pt} = 5.27 \text{ fm}$
- $q_t^2 = t - t_{min}$ , is the square of the transverse momentum transfer to the nucleus.

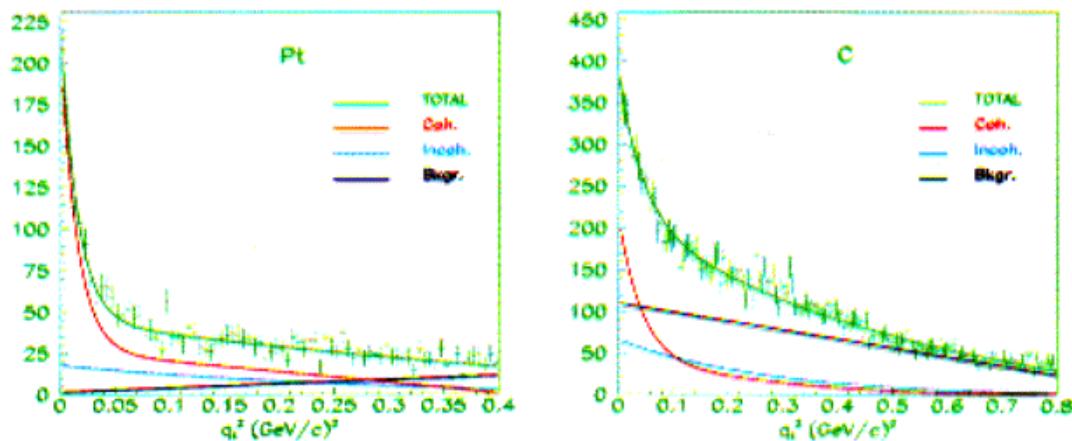
$q_t^2 = \text{mom. transf to nucleus}$



## A DEPENDENCE OF DIFFRACTIVE YIELD

1. Combine the reconstructed MC distributions of Pt + N for the coherent and incoherent interactions with the nucleus.
  2. Fit the combination to the data of Pt.
  3. Repeat for carbon.
  4. The parameters of the fit give the total normalization factor between MC and DATA and coherent/incoherent dissociation.
- Integrate over the diffractive peaks (of Pt and C) in the generated MC multiplied by the total normalization factor between MC and DATA.

$$1.5 \leq k_t < 2.0 \text{ GeV}/c$$



PRELIMINARY RESULT:  $\sigma \propto A^n$

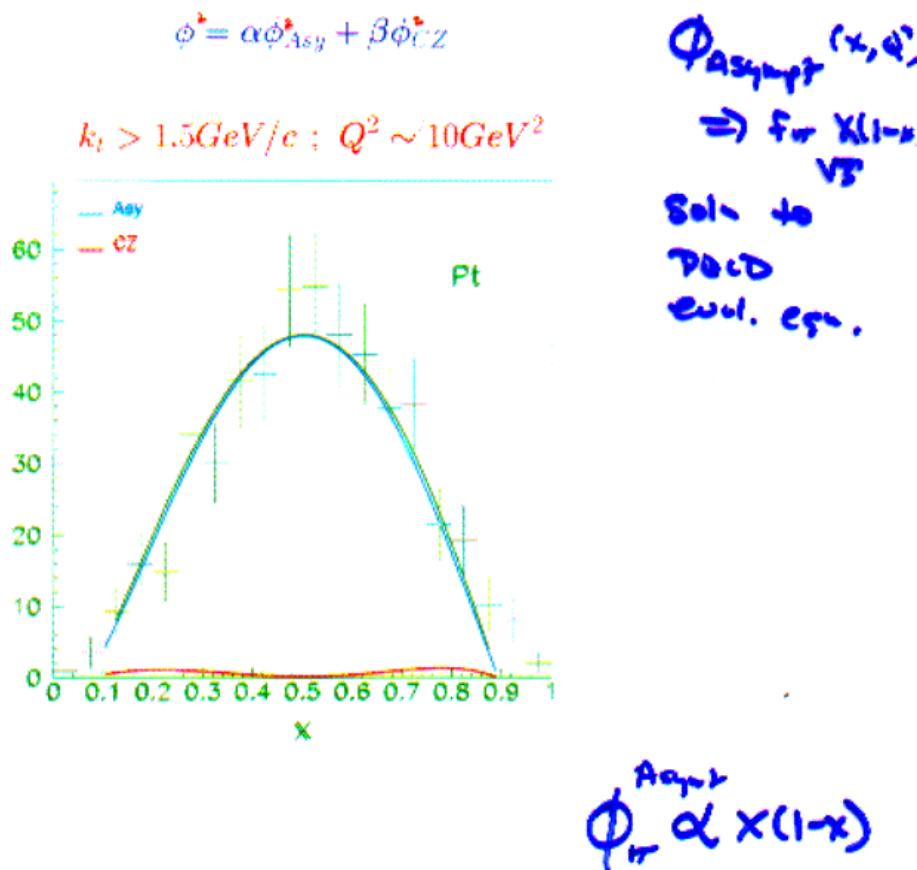
<u><math>k_t</math> range (GeV/c)</u>	<u><math>\alpha</math></u>	<u><math>\alpha</math> (CT)</u>	<u><math>\alpha</math> (Incoh.)</u>
$1.5 < k_t < 2.0$	$1.61 \pm 0.08$	$1.45$	$0.70 \pm 0.1$
$2.0 < k_t$	$1.65 \pm 0.09$	$1.60$	

$\Rightarrow \sigma(Pt)/\sigma(C) \sim 87$  compare with  $\sim 7$  for  $A^{\frac{2}{3}}$

- ✗ Nucleus transparent to  
Fock State of Proton
  - ✗ Color Transparency
-

**E791 DATA - THE  $q\bar{q}$  MOMENTUM WAVE  
FUNCTION  
AS MEASURED BY THE DI-JETS**

- Use the diffractive di-jets to extract the momentum  $x$  distribution.
- Fit to a combination of the two wave function simulations.



PRELIMINARY: > 90% Asymptotic W.F.

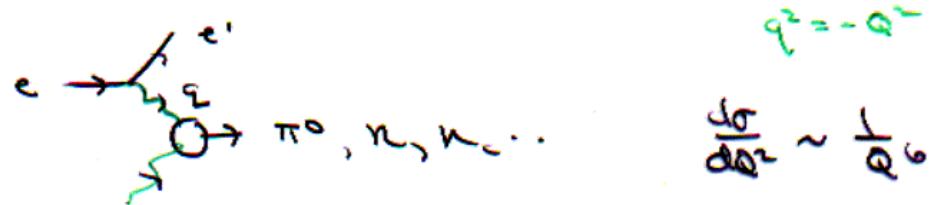
Same  $q_3$   
 seen in  
 $F_{\gamma \rightarrow \pi 0}(Q^2)$

E791 Except:

- \* Sensitive to small size component in projectile form
- \* Nucleus left intact
- \* Coherent, Every nucleon contributes
- \* High enough energy  $t_{min} \sim 0$
- \* Component does not expand during transit thru nuclei
- \* Coln transparency
- \*  $\phi_\pi(x) \propto x(1-x)$ 
  - asymptotic soln
  - to and eqn

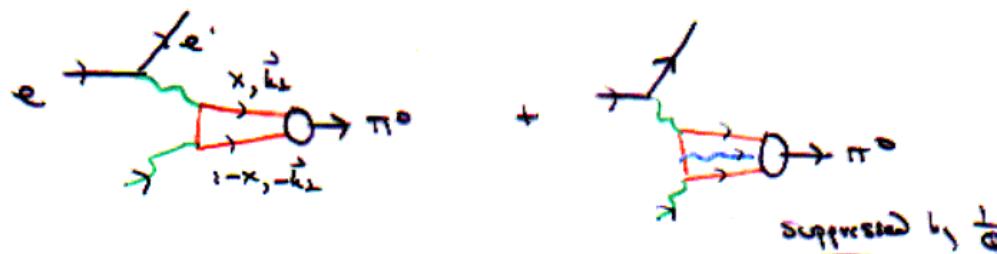
$$\int_0^1 dx \phi_\pi(x) = \text{Fr} \frac{2}{\sqrt{3}}$$

Simplest example of exclusive process



$$Q^2 \gg \lambda_{\text{QCD}}^2$$

$$F_{\gamma\pi^0}(Q^2)$$



$$F_{\gamma\pi^0}(Q^2) = \frac{1}{Q^2} 2\sqrt{N_c} (\bar{c}_u^2 - \bar{c}_d^2) \int_0^1 \frac{dx}{x(1-x)} \phi_\pi(x, \tilde{Q})$$

Pion  
distribution  
amplitude

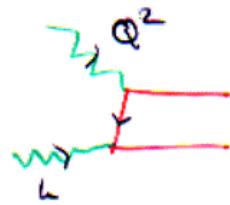
$$\phi_\pi(x, \tilde{Q}) = \int \frac{d^2 k_L}{16\pi^3} \Psi_{qq}^{(5)}(x, k_\perp)$$

$$\int_0^1 dx \phi_\pi(x, Q) = \frac{f_\pi}{2\sqrt{2}}$$

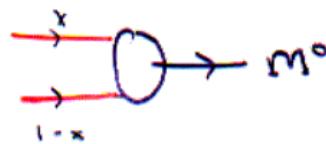


SAS  
Lepage

DQCD :  $F_{\gamma \rightarrow M^0}(Q^2) \sim \frac{1}{Q^2} \int_0^1 \frac{dx}{1-x} \phi_m(x, Q)$



$T_H$



$$\phi_m(x, Q) = \int d^2 b_\perp \Phi_{q\bar{q}}(x, b_\perp)$$

\*  $T_H (\gamma^* \gamma \rightarrow q \bar{q}) \sim \frac{1}{Q^2(1-x)} \Theta(Q^2)$  collinear

\* Higher Fock states :  $\frac{1}{Q^4}$  = 0

Other diagrams  $\Theta(\alpha_s(Q^2))$ !

\*  $\phi_m(x, Q) = \sum_{n=0}^{\infty} Q_n P_n(x) \left(\ln \frac{Q^2}{Q_0^2}\right)^{-k_n}$  III log evolution

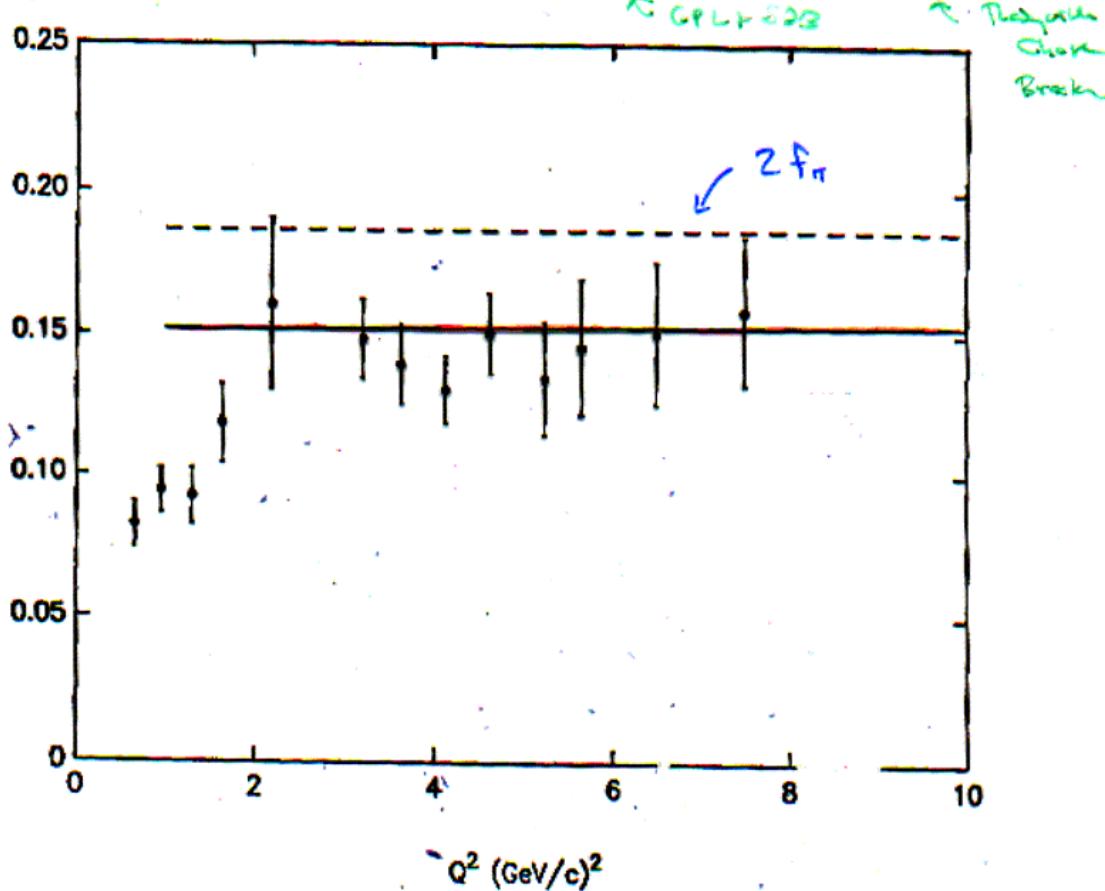
\*  $\lambda_n = \lambda_q + \lambda_{\bar{q}} = 0.$

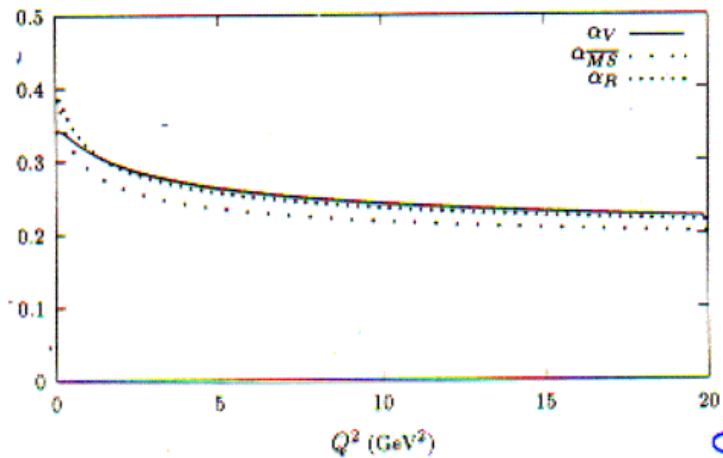
\*\* Small part of Fock state dominates

$$\phi_m \sim \Phi(x, b_\perp \sim \frac{1}{Q})$$

$$\phi = \phi_{asympt} \\ = \sqrt{2} \times (1-x) f_\pi$$

$$Q^2 F_{\pi\gamma}(Q^2) = 2f_\pi \left[ 1 - \frac{\pi}{3\pi} \alpha_V(e^{-3Q^2}) \right]$$



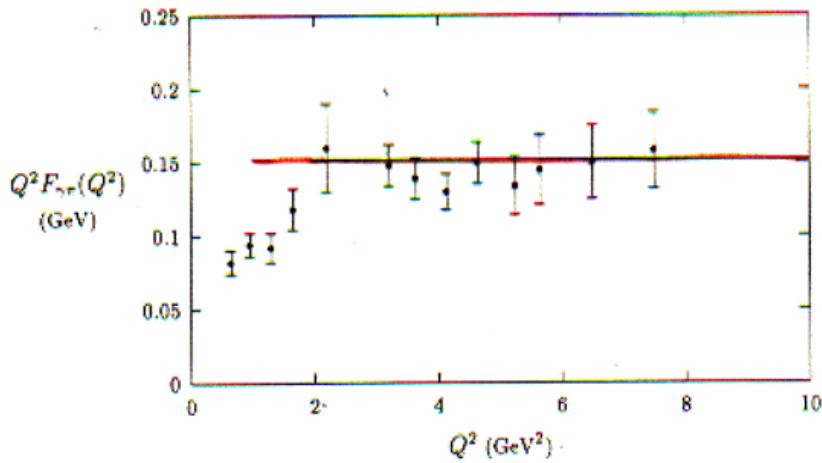


$\alpha_V$  from

Commuensurate  
Scale rels

Charge  
Renormalon  
Broken

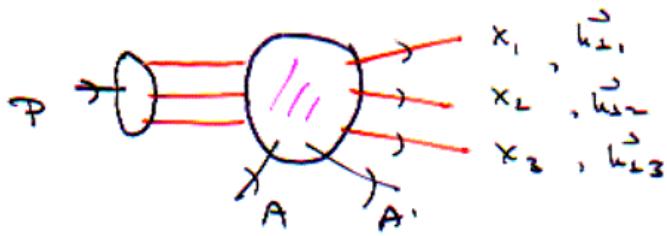
$$Q^2 F_{\pi\gamma}(Q^2) = 2F_\pi \left[ 1 - \frac{5}{3} \frac{\kappa_V}{\pi} e^{-\kappa V Q^2} \right] \quad \text{NLO}$$



Data:  
CLEO (97)  
Savmon

$$\phi_\pi(x) = \phi_{\pi\gamma\gamma\pi} = \sqrt{2} F_\pi x(1-x)$$

## Nuclear Diffraction



Test at HERA-B  
FNAL, RHIC?

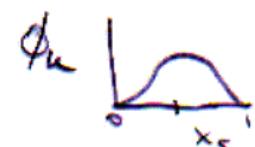
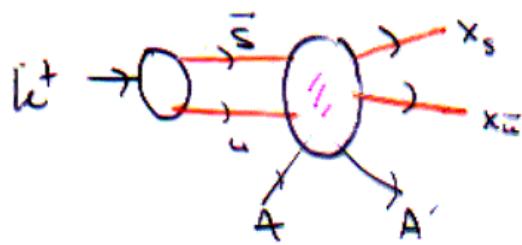
$$\sum x_i \leq 2$$

$$\sum \vec{k}_{i\perp} \equiv \vec{0}_\perp$$

Frankfurt  
Strikman  
Miller

measure nucleon  $\Psi_{sq}(x_i, \vec{k}_{i\perp})$

Factinucleon



$$\langle x_s \rangle > \frac{1}{2} ?$$

M. Diehl  
A. Martin et al.



$$G_T : x^2 + (1-x)^2$$

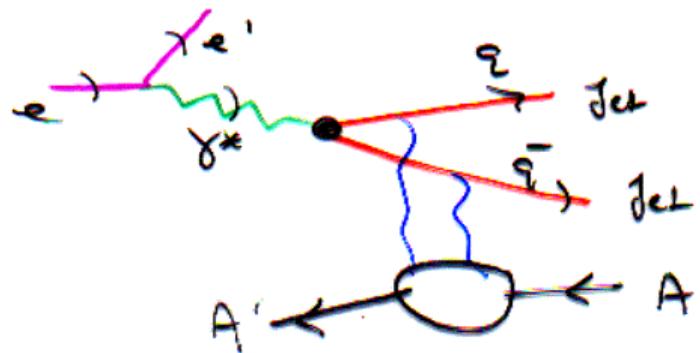
$$G_L : x(1-x)$$

measure  $\Psi_{\bar{q}q/\gamma^*}(x, k_\perp)$  charm component

$e A \rightarrow e' A' J J$  rapidity gap

Hoyer, Magnea, SSB

Resolve photon at eRHIC



Determine  $\Psi_{q\bar{q}/\gamma^*}(x, \vec{h}_\perp, \lambda)$

$eA \rightarrow e' A' \text{ Jet Jet}$

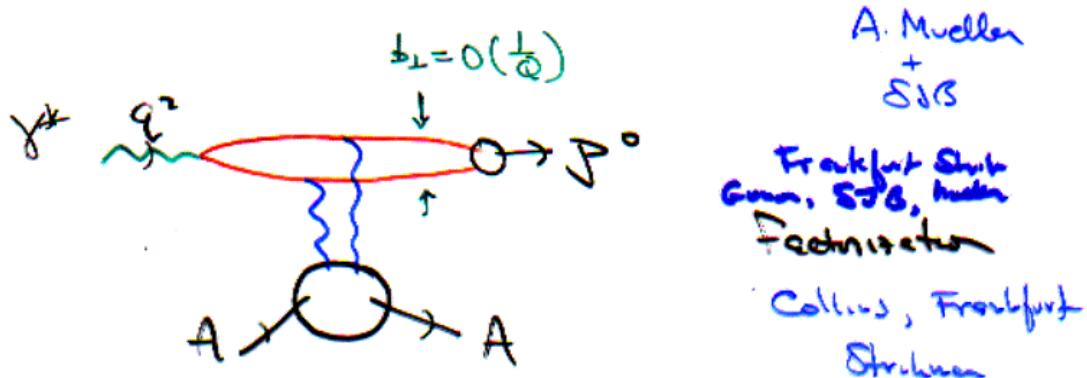
rapidity gap

$$\text{PQCD: } \sigma_r : x^2 + (1-x)^2$$

$$\sigma_L : x(1-x)$$

Non-perturbative modifications at small  $h_\perp$

## Color Transparency and Hard Diffraction



Fluctuation stays compact as  
it transits nucleus

∴ A dependence coherent:  $g_A(\vec{x}) \sim A^{\frac{1}{3}}$   
modulo gluon shadowing

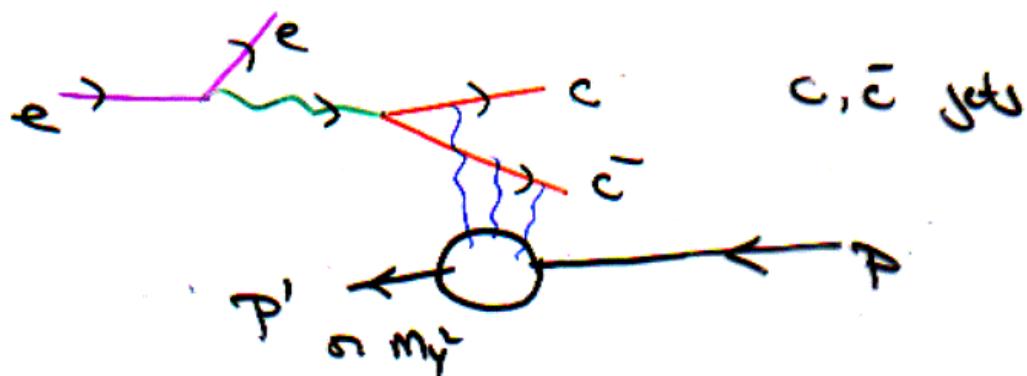
$$t=0: M_{\gamma A \rightarrow \pi^0 A} \approx A M_{\gamma p \rightarrow \pi^0 p}$$

\*  $\int dt \frac{d\sigma}{dt} (\gamma^* A \rightarrow \pi^0 A) = \frac{A^2}{R_A^2} \sim A^{1/3}$

\* Also: quasi-elastic  $\sigma_A \sim A \sigma_N$

## Odderon - Pomeron Interference

at HERA, ERHIC



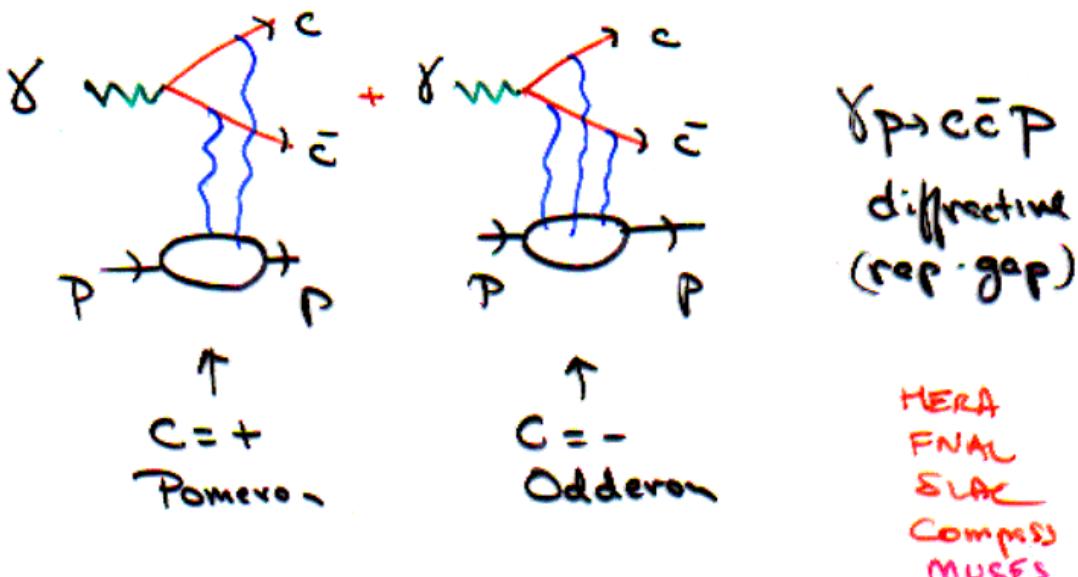
$$S \gg 4m_c^2$$

Measure  $\bar{z}_c$  vs  $\bar{z}_{\bar{c}}$

Nuclear Dependence of  
Pomeron, Odderon

## Measure Odderon-Pomeron Interference

J. Rathsman  
C. Moreno, SJSU



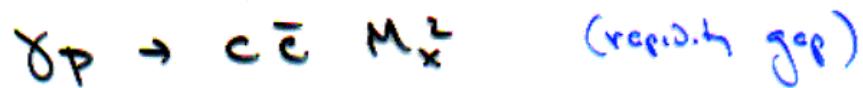
Interference gives  $c \leftrightarrow \bar{c}$  asymmetry:

$$A = \frac{\frac{d\sigma}{dt dm^2 dz_c} - \frac{d\sigma}{dt dm^2 dz_{\bar{c}}}}{\frac{d\sigma}{dt dm^2 dz_c} + \frac{d\sigma}{dt dm^2 dz_{\bar{c}}}}$$

$$\propto \sin \left[ \pi \frac{(\alpha_O - \alpha_P)}{2} \right] S^{\alpha_O - \alpha_P}$$

$$\frac{2z_c - 1}{z_c^2 + (1-z_c)^2}$$

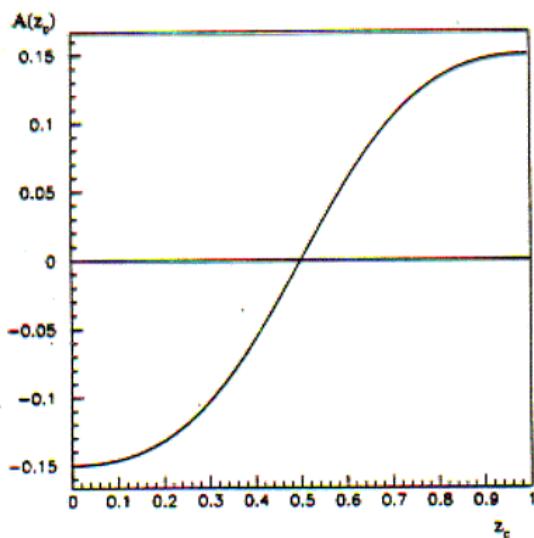
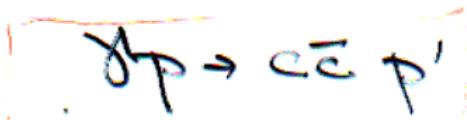
How to Measure the  
Odderon-Pomeron Interference  
at e-p colliders



look for  $c$  vs  $\bar{c}$  asymmetry !

$$A = \frac{\sigma(E_c > E_{\bar{c}}) - \sigma(E_{\bar{c}} > E_c)}{\sigma(E_c > E_{\bar{c}}) + \sigma(E_{\bar{c}} > E_c)}$$

$$A(t, M_X^2, z_c) = \frac{\frac{d\sigma}{dt dM_X^2 dz_c} - \frac{d\sigma}{dt dM_X^2}}{+}$$



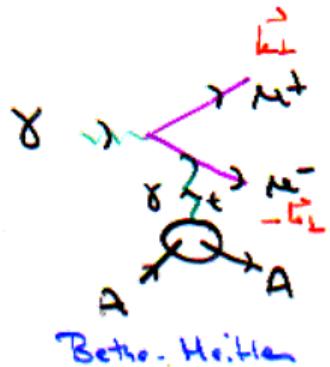
estimate

$$A(t=0, M_X^2, z_c) \approx 0.3 \left( \frac{S_{\gamma p}}{M_X^2} \right)^{-0.18} \frac{z_c - 1}{z_c^2 + (1-z_c)}$$

magnitude saturates  
 $\gamma p$  vs  $\bar{\gamma} p$

## Coulomb Dissociation

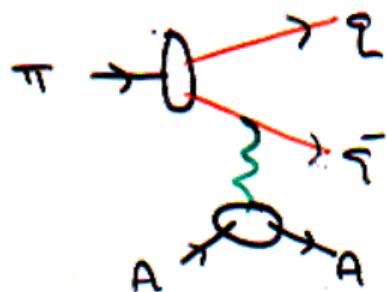
P. Kogar, S. Peigne  
SJB



$$\frac{d\sigma}{dt dk_{\perp}^2} \approx \frac{\alpha(2\alpha)^2}{k_{\perp}^4} \frac{F_e(t)}{t}$$

measure  $\phi_{\gamma}(x)$

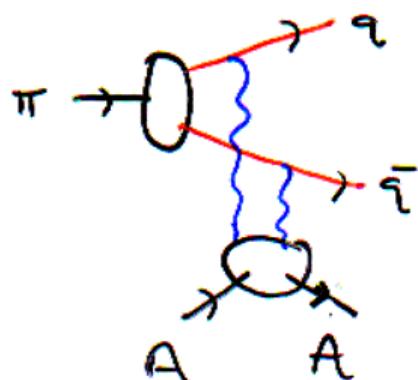
pion dissociation to jets also has Coulomb component



$$\frac{d\sigma}{dt dk_{\perp}^2} \approx \frac{f_{\pi}^2 (2\alpha)^2}{k_{\perp}^4} \frac{F_q(t)}{t}$$

↑  
gives  $\log$

Hiller, Strikman, Franklin

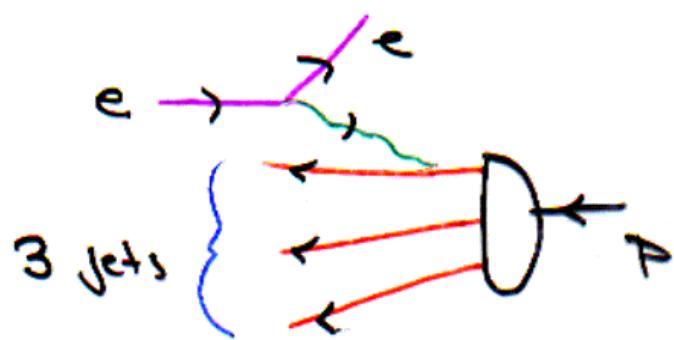


$$\frac{d\sigma}{dt dk_{\perp}^2} \approx \frac{f_{\pi}^2 \alpha_s^2 q^2(\bar{x}) A^2 F_A(t)}{k_{\perp}^8}$$

$\bar{x}$  may be comparable at large  $k_{\perp}$

both measure  $\phi_{\pi}(x)$

## Diffractive Dissociation of the Proton



$$\sum k_{\perp} = q_{\perp} \approx 0$$

$$\sum x_i = 1$$

$q^2 \sim 0$   
Frankfurt  
Strikman  
Peggs, Kogee,  
SJSB  
CERNweb D 1800

e- $\bar{p}$   
Collider  
expt

Use E791 techniques

Ashery, et al.

measure  $\Psi_{gg}^P(x_i, k_{2n})$

non-symmetric  $\phi_p(x_i, Q)$  ?

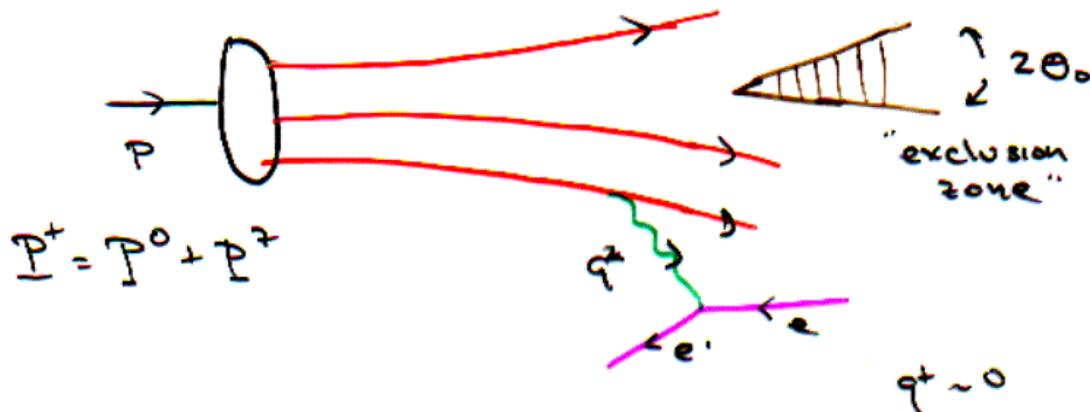
$$\Psi \sim \frac{g_s(h^2)}{h^2}$$

"Self-Resolving" Jet Reactions at eRHIC

nogen  
Perge  
Dichi  
838

(impros.)

$$ep \rightarrow e^- \text{ Jet Jet Jet}$$



Coulomb dissociation of proton

Require

$$\frac{|k_{\perp i}|}{k_i^+} > \sin \theta_0 \quad , \quad \sum_i k_i^+ \approx P^+$$

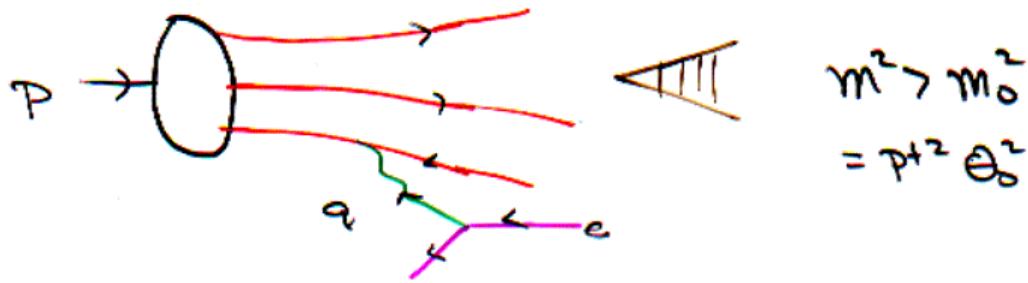
(all  $i$ )

$$\therefore k_{\perp i}^2 > x_i^2 P^2 \sin^2 \theta_0$$

$$\begin{aligned} m^2 &= \sum_i \left( \frac{k_{\perp i}^2 + m^2}{x_i} \right) \rightarrow \sum_i x_i P^2 \sin^2 \theta_0 \\ &= P^2 \sin^2 \theta_0 \end{aligned}$$

∴ exclusion zone selects invariant mass

Estimate of cross section:



$$\text{Amp} \sim \sum e_i q_{\perp}^2 \cdot \frac{\partial}{\partial k_{\perp i}} \Psi_{\perp}(x_i, k_{\perp i}, \lambda_i)$$

$$P(x_i, m_0^2) = \int \left| \frac{\partial}{\partial k_{\perp i}} \Psi_{\perp}(x_i, k_{\perp i}) \right|^2$$

$$\prod_{i=1}^2 d^3 k_{\perp i} \Theta(\sum \frac{k_{\perp i}^2 + m^2}{x} > m_0^2)$$

$$\frac{d\sigma}{d \ln q_{\perp}^2 dx_i dk_{\perp i}} (m^2 > m_0^2) \sim \alpha^2 P(x_i, m_0^2)$$

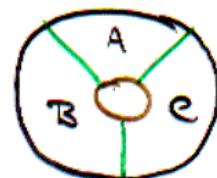
$$\sim \frac{\alpha^2 f_N}{(m_0^2)^3} |\phi(x_i)|^2$$

$$\langle f_N \rangle \sim \pi^2$$

## Experimental Measures

ep ✗  $\frac{d\sigma}{dm^2} \sim \left(\frac{1}{m^2}\right)^n$   $\left(\frac{1}{m^2}\right)^6$  for pA

- ✗ Jet structure
- ✗  $x_i$  - distribution
- ✗ measure  $\frac{x_B}{x_A}, \frac{x_c}{x_A}$

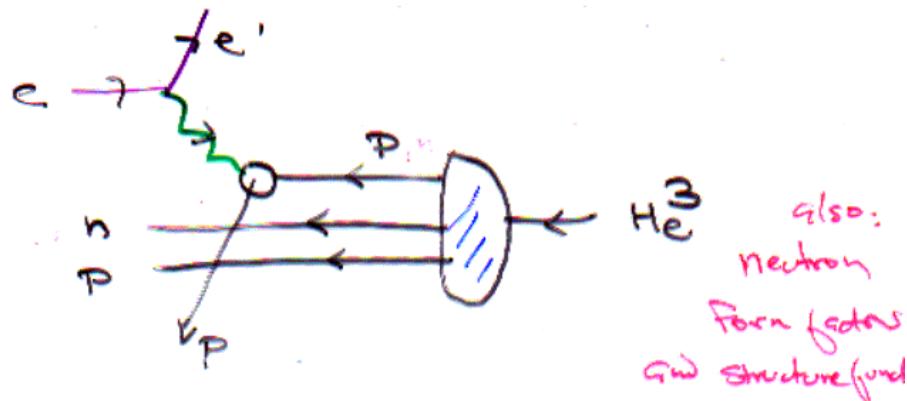


$$x_A > x_B > x_C$$

$e p \uparrow \rightarrow e' \text{ Jet Jet Jet}$

- ✗ proton polarized normal  look for oblate dist.  
Sphericity variables
- ✗ Connection to proton distribution amplitudes  
Same tools for  $pA \rightarrow p' \text{ jet jet jet}$   
at RHIC (pA)

## Nuclear Physics and Fragmentation

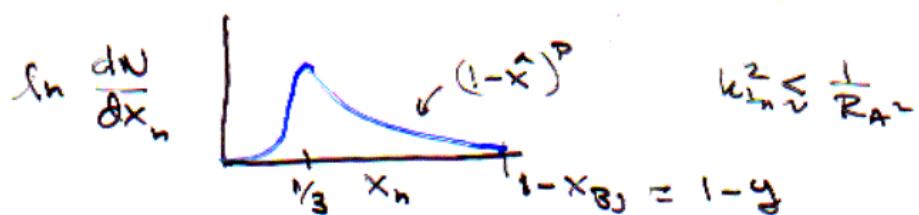


Measure  $x_n = \frac{k_n^+}{P_{He^3}^+} = \frac{(k^0 + k^3)_n}{(P^0 + P^3)_{He^3}}$

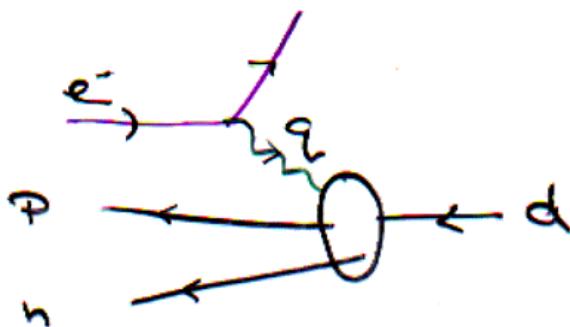
$\vec{x}_n, \vec{k}_{in}$  : reflects  $\psi^{LC}(x_i, \vec{k}_i, \lambda)$

Relativistic nuclear physics!

\*  $\psi^{LC} \Rightarrow \psi^{\text{Schrodinger}}$  in non-rel domain

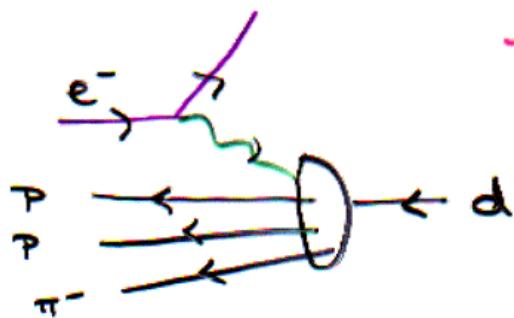


## Self-Resolving Nuclear Interactions

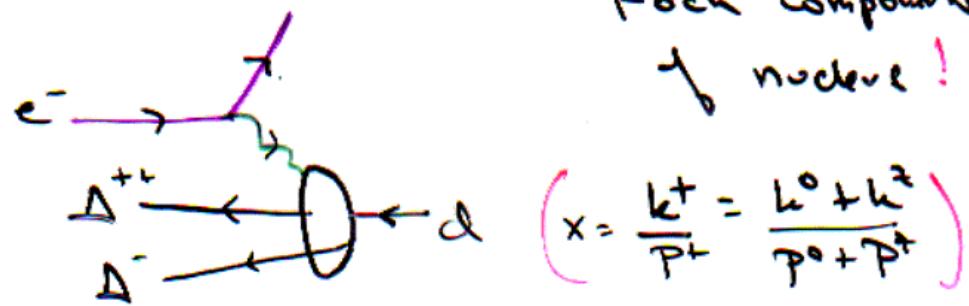


Hoyer  
Perigee  
SGB

$$q_{\perp}^2 \ll \langle h_{\perp}^2 \rangle$$



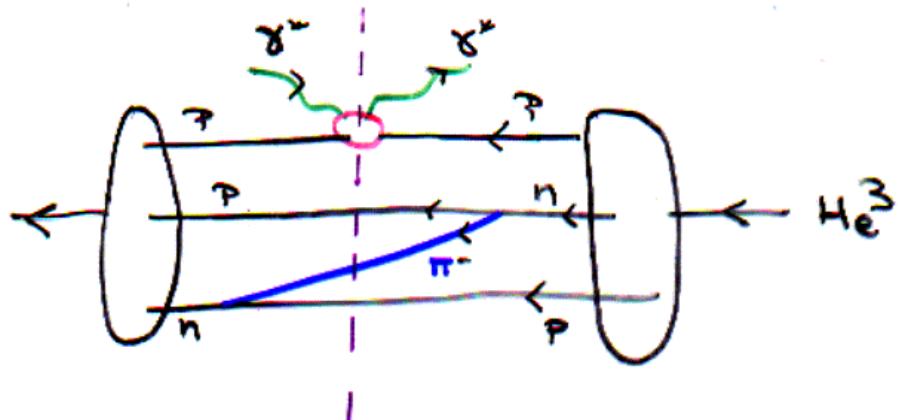
— photon acts last



measure all  
Fock components  
↓ nucleon!

\* measures  $\sum_i e_i \frac{\partial}{\partial h_{2i}} \Psi_d(x_i, h_{2i}, \lambda)$

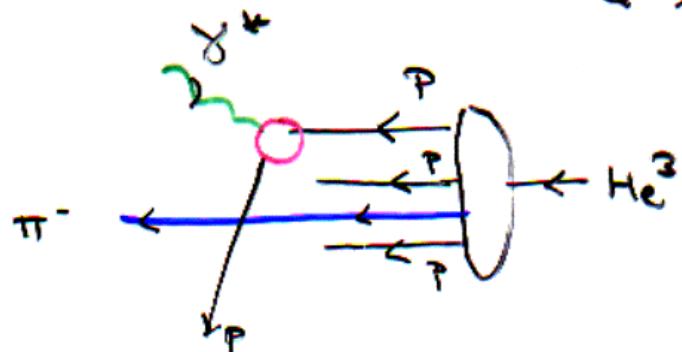
## Measure Meson Exchange in Flight



\* resolve  $\Psi_{PPP\pi^-/He^3}$  at fixed  $T$

$$y = x = k^+_p / k^+_{He^3}$$

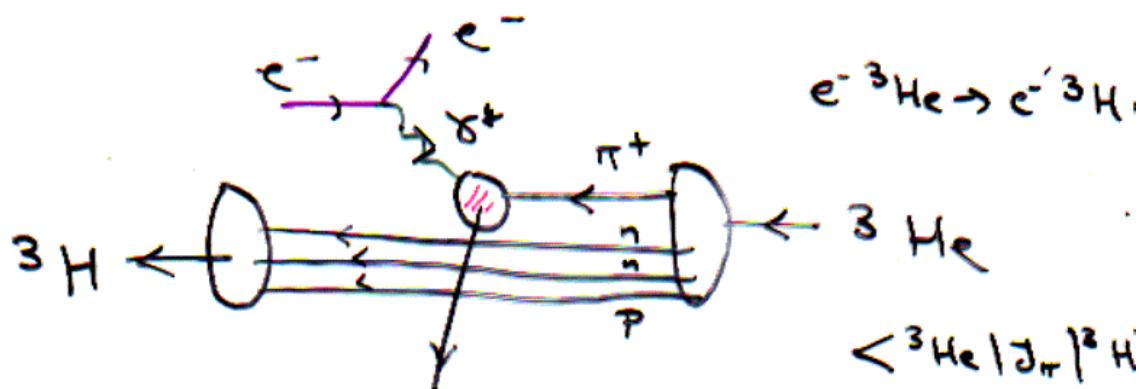
y scaling at  
 $Q^2 > \langle u_\Sigma \rangle$



\* resolve  $\Psi_{PPP\pi^-/He^3}(x_i, k^+_\pi, \lambda)$

\* Subtract  $n \rightarrow p \pi^-$  by convolution.  
 $\Psi_{pnp} * \Psi_{p\pi^-/n}$

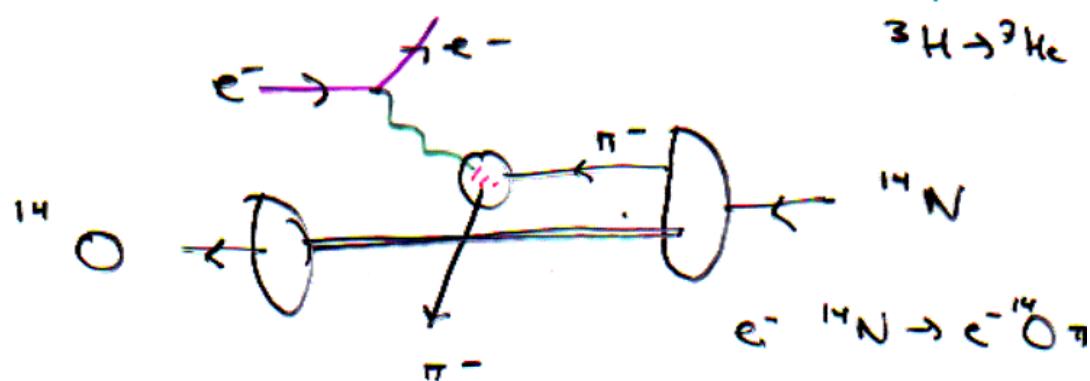
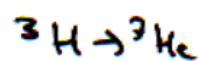
## Nuclear - Coherent Meson Production



Kortner, Miller  
SAB

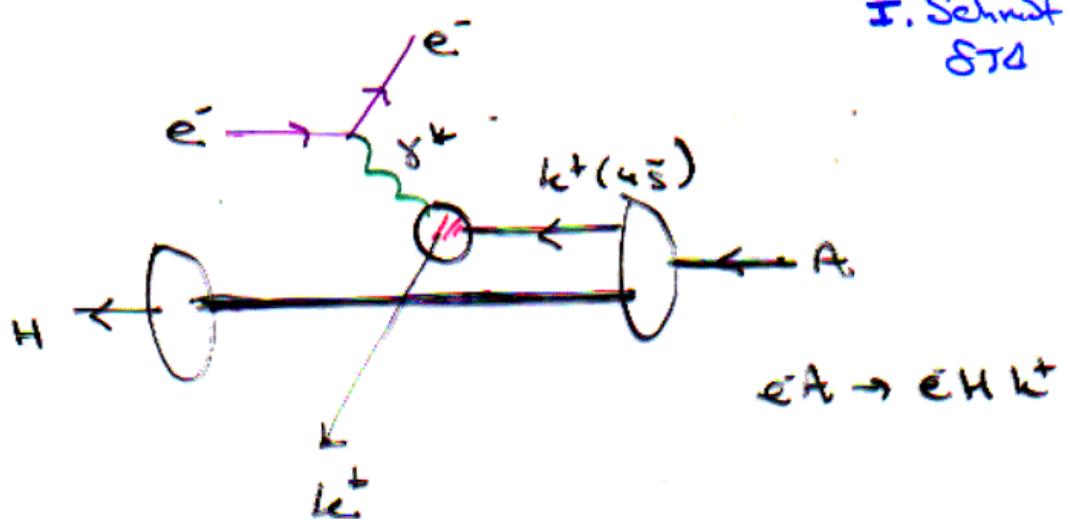
$\pi^+$

normalize via PCF  
to  $\beta$ -decay



produce "beams" of nucleides  
magnetic Spectrometers

## Nuclear - Coherent Hypernucleus Production



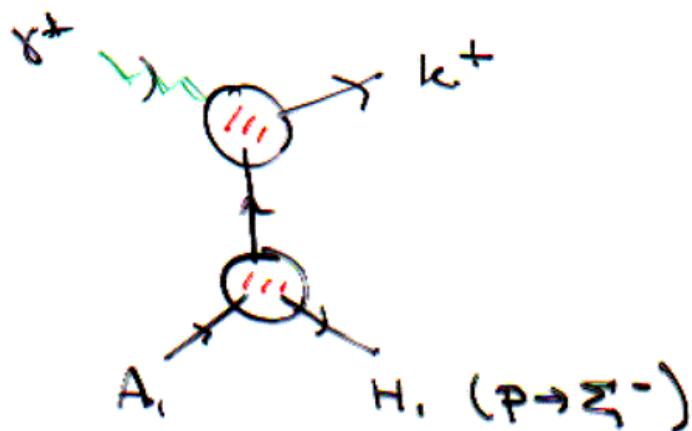
replace  $u$  by  $s$  to form hypernucleus  
 $H$

produce "beam" of hypernuclei

also: HERA, ERHIC.

magnetic spectrometer

## Extensions



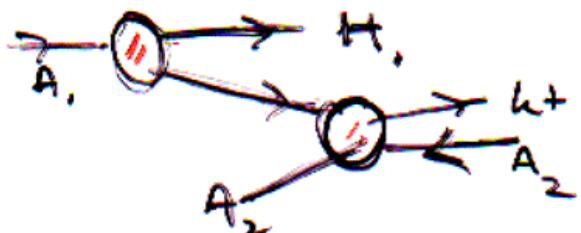
measure  $k^+$  structure function, form factor

produce hypernuclei

relativistic hypernuclei at HERA (eA)

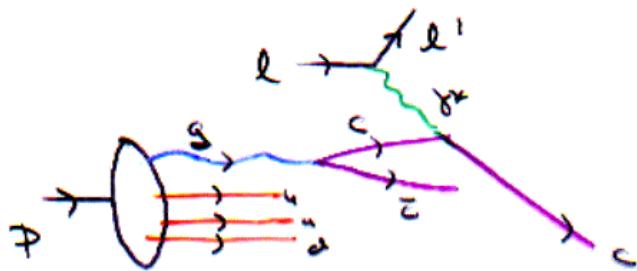
associated production

SJG  
+ I. Schmidt

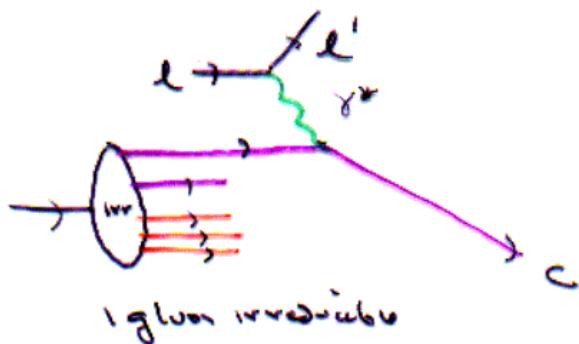


RHIC  
relativistic  
hyperons

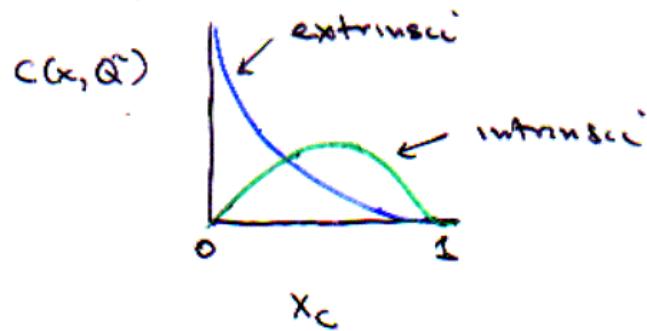
## Two contributions to Sea Quark Distributions



extrinsic =  
photon-gluon  
fusion  
 $g\gamma^*\rightarrow c\bar{c}$



intrinsic  
initial state  
for DGLAP  
evolution



$$Q^2 \gg 4m_c^2$$

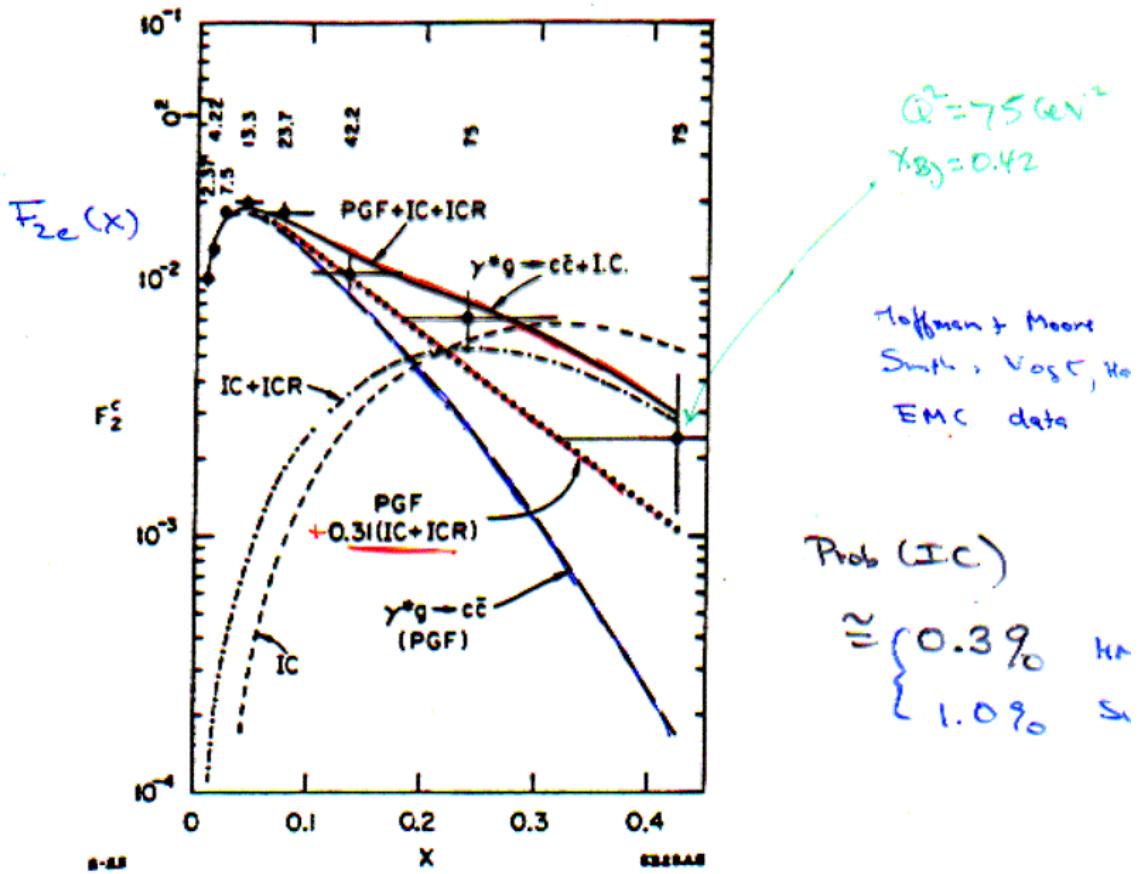
$$C_I \propto \frac{1}{m_c^2 R^2}$$

Vogt

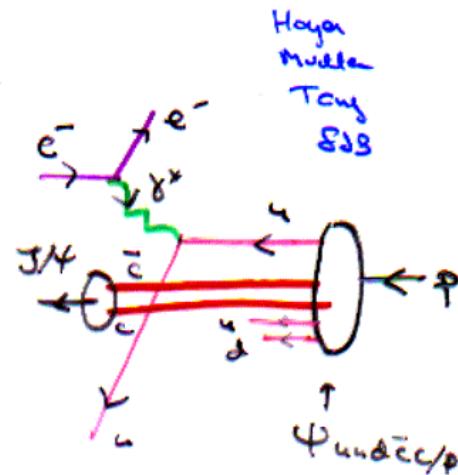
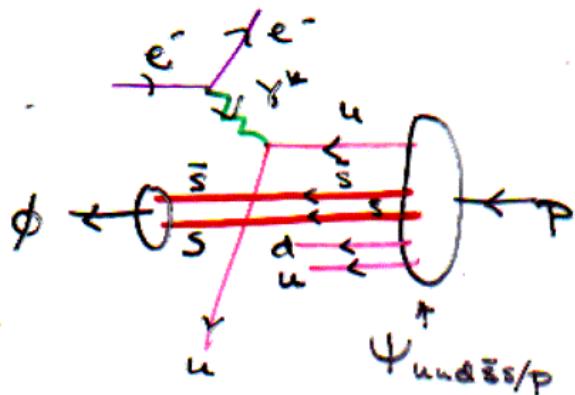
SJG, Vogt, Sola,  
Peccei

Thomas

Engdahl & Thomas



eRHIC: New Tests of Intrinsic { Strangeness ✓  
Charm ?

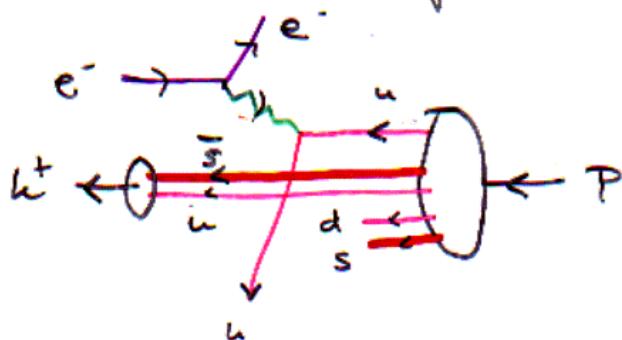


- $\phi, J/\psi$  created after  $\gamma^*$  line,  $Q^2 > 4m_Q^2$

- coalescence of  $s\bar{s}$  into  $\phi$

via  $\Psi_{s\bar{s}/\phi}(x, \tilde{t}_2, \lambda)$

- polarization of  $\phi, J/\psi$  crucial test

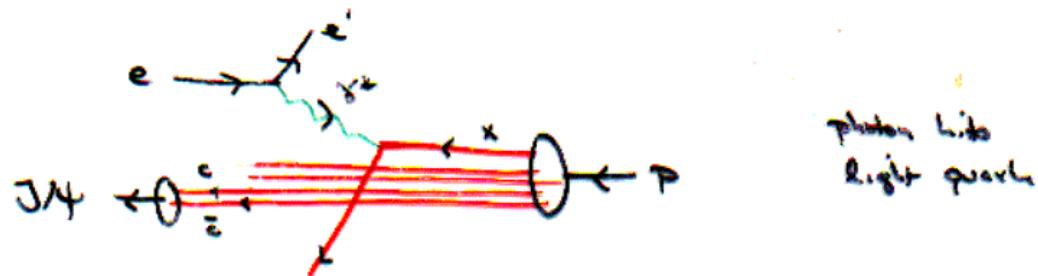


- coalescence of  $u\bar{s}$

$\Psi_{u\bar{s}/k^+}(x, \tilde{t}_2, \lambda)$

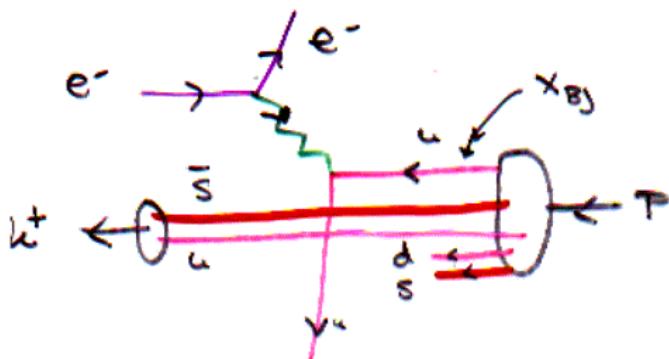
DSB  
P. Kotey  
A. Mueller  
W. Tang

Test of BHMT/ Intrinsic Charm  
in J/ψ production



- \* J/ψ produced at low  $P_T \sim 0(M_e)$ 
  - \* large  $\hat{z} = \frac{P_{J/\psi}}{(1-x) P^+}$
  - \*  $y_{J/\psi} \sim y_P$
- \*  $P_T(J/\psi)$  independent of  $Q^2$  !
- \* J/ψ from intrinsic structure of proton.
- \* polarization transfer at large  $\hat{z}(J/\psi)$
- \*  $\sigma^{xx}(Q^2) \sim \frac{1}{Q^2 m_c^2}$  large  $Q^2$ ;  $\sigma \sim \frac{1}{m_c^2}$ ,  $Q^2 \ll \pi$

## $x \Rightarrow 1$ "Counting Rules" for Fragmentation



$$\hat{x}_k = \frac{k_{L^+}^+}{p^+ - k^+} = \frac{k_{L^+}^+}{p^+(1-x_B)} \quad (0 < \hat{x}_k < 1)$$

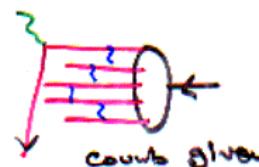
\*  $\frac{dN}{d\hat{x}_k} \propto (1-\hat{x}_k)^{2n_{\text{spect}}-1 + 2|\Delta S|}$

Lepage  
Gunion  
Bauer-Bearden  
SJR

Here:  $n_{\text{spect}} = 2 \quad (d, s)$

$$\Delta S = |\lambda_{L^+} - \lambda_P| = \frac{\gamma}{2}$$

$$\frac{dN}{d\hat{x}_k} \propto (1-\hat{x}_k)^4$$



## Semi-Exclusive Processes

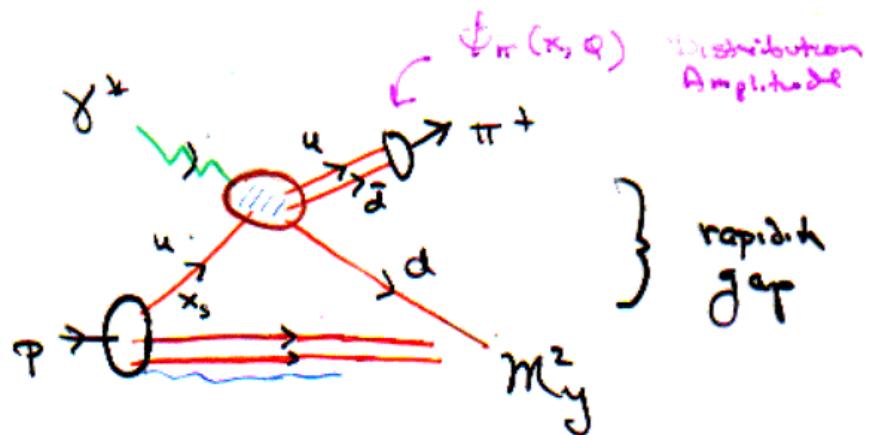
$$\left\{ \begin{array}{l} A + B \rightarrow C + Y \\ \gamma^* p \rightarrow \pi^+ + Y \end{array} \right.$$

- Generalized Currents
  - New Probes of Hadron Structure

M. Dicht, P. Hoyer  
S. Peigne, SSB

\* See also "Direct Processes"

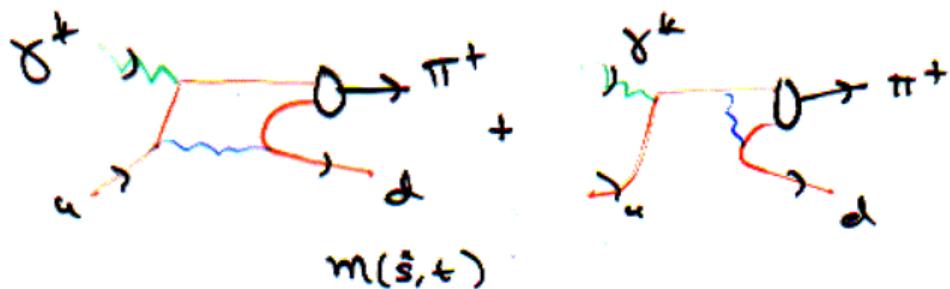
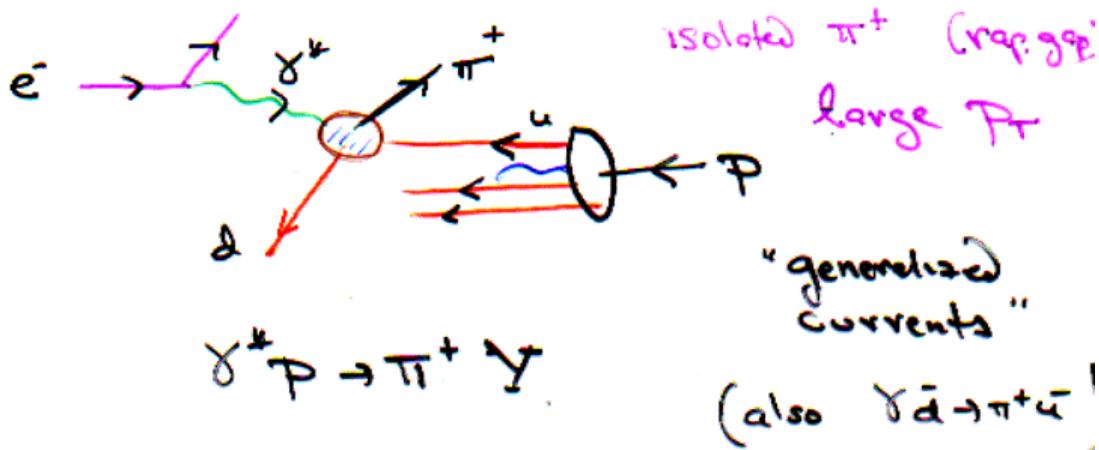
Carlson + Wakely  
Blauenthaler, Gurwitz Sovt., § 30



$$\frac{d\sigma}{dt dx_s} (AB \rightarrow C D) = \sum_b f_{b/B}(x_s, \mu^2) \frac{d\sigma}{dt} (Ab \rightarrow Cd)$$

$$x_s = \frac{-t}{m_y^2 - t}$$

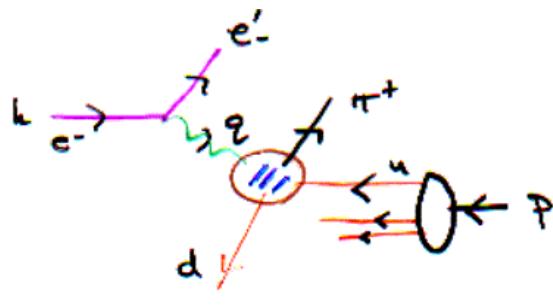
## Semi-Exclusive Processes



$$+\frac{d\sigma}{dt} (\gamma u \rightarrow \pi^+ d) = \frac{128\pi^2}{27} \alpha \alpha_s^2 \frac{(e_u - e_d)^2}{\hat{s}^2(-t)}$$

$$\times \left\{ \left[ \int_0^1 dz \frac{\phi_\pi(z)}{z} \right]^2 + \left[ \int_0^1 dz \frac{\phi_\pi(z)}{1-z} \right]^2 \right\}$$

$$= \frac{16\pi^2}{9} \alpha \alpha_s^2 \frac{-t |F_{\pi\pi}(-t)|^2}{\hat{s}^2}$$



dominance of  $\sigma_L$   
at large  $Q^2$ , small  $t$

$$y = \frac{p \cdot q}{q \cdot k} = \frac{v}{\epsilon_a}$$

$$x = -\frac{q^2}{2p \cdot q}$$

$$x_s = -\frac{t}{M_\nu^2 - t}$$

$$t = (p_\pi - q)^2$$

$$\hat{s} = (x_s p + q)^2$$

$$\frac{d\sigma}{dQ^2 dx_B, dt dx_S} = \frac{\alpha}{\pi} \frac{1-y}{Q^2 x_B} \frac{512\pi^2}{27} \alpha_s^2 \frac{x_B}{\hat{s} Q^4}$$

$$\left\{ \int_0^1 dz \frac{\Phi_\pi(z)}{z} \right\}.$$

$$\left\{ \begin{aligned} & u(x_s) \left[ e_u + \left(1 - \frac{x_B}{x_s}\right) e_d \right]^2 \\ & + \bar{d}(x_s) \left[ e_d + \left(1 - \frac{x_B}{x_s}\right) e_u \right]^2 \end{aligned} \right\}$$

## Features of Semi-Eclusive Processes

- \* Generalized Currents : Spin, transversely
- \* Color transparency in  $\gamma^* p \rightarrow \pi^+ Y$   
Small  $\pi$  at large  $P_T$
- \* Strange quark probe  
 $\gamma^* p \rightarrow K Y, \phi Y$   
ratios
- \* Scaling law  
 $\frac{d\sigma}{dt}(\gamma q \rightarrow nq) \propto \frac{1}{s} f(t/s)$
- \* Evolution of  $\phi_m, q(x_s)$
- \* Vector mesons:  $V_T$  suppressed
- \* Odderon, Pomeron Exchange  
in  $\gamma p \rightarrow \pi^0 Y$